# Effects of transcription ability and transcription mode on translation:

## Evidence from written compositions, language bursts and pauses when students in grades 4 to 9, with and without persisting dyslexia or dysgraphia, compose by pen or by keyboard

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**Abstract:** This study explored the effects of transcription on translation products and processes of adolescent students in grades 4 to 9 with and without persisting specific language disabilities in written language (SLDs—WL). To operationalize transcription ability (handwriting and spelling) and transcription mode (by pen on digital tablet or by standard US keyboard), diagnostic groups contrasting in patterns of transcription ability were compared while composing autobiographical (personal) narratives by handwriting or by keyboarding: Typically developing students (n=15), students with dyslexia (impaired word reading and spelling, n=20), and students with dysgraphia (impaired handwriting, n=19). They were compared on seven outcomes: total words composed, total composing time, words per minute, percent of spelling errors, average length of pauses, average number of pauses per minute, and average length of language bursts. They were also compared on automaticity of transcription modes—writing the alphabet from memory by handwriting or keyboarding (they could look at keys).

Mixed ANOVAs yielded main effects for diagnostic group on percent of spelling errors, words per minute, and length of language burst. Main effects for transcription modes were found for automaticity of writing modes, total words composed, words per minute, and length of language bursts; there were no significant interactions. Regardless of mode, the dyslexia group had more

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spelling errors, showed a slower rate of composing, and produced shorter language bursts than the typical group. The total number of words, total time composing, words composed per minute, and pauses per minute were greater for keyboarding than handwriting, but length of language bursts was greater for handwriting. Implications of these results for conceptual models of composing and educational assessment practices are discussed.

**Keywords**: transcription, translation, keyboarding, handwriting, dyslexia, dysgraphia, language bursts

Writing is challenging for most students, but it is particularly difficult for students with specific learning disabilities in written language (SLDs—WL) affecting transcription (handwriting and spelling). In the US, writing achievement scores for all students consistently lag behind reading and math scores. According to the 2011 results of the National Assessment of Educational Progress (NAEP, U.S Dept. of Education), only 27% of students scored at the *proficient* or *advanced* level in writing, at both the eighth grade and twelfth grade levels. Furthermore, one in five students scored at the *below basic* level (*basic* levels indicate "partial mastery") in writing at these grade levels (20% and 21%, respectively). For students with disabilities, the national assessment results are even more sobering. At both the eighth and twelfth grades, only 5% of students with disabilities reached the *proficient* level in writing in 2011, while three out of five (60% and 62% respectively) scored at *below basic* levels in writing. Writing problems may emerge early in development (von Koss Torkildsen, Morken, Helland, & Helland (2016) and respond to early intervention (Berninger, 2009), but also sometimes persist during the upper elementary and middle school grades despite early intervention, when writing requirements increase (Berninger, Richards, & Abbott, 2015).

## 1. Specific Learning Disabilities in Writing

Students may have disabilities in writing for a variety of reasons, ranging from pervasive or specific developmental disabilities or low incident neurogenetic disorders or congenital brain disorders to acquired brain injuries (see Batshaw, Roizen, & Lotrecchinao, 2013) or specific learning disabilities (SLDs) in otherwise typically developing and neurologically intact individuals (Berninger, 2015). Drawing on neuropsychological research evidence, Berninger (2004) differentiated between developmental dysgraphia and developmental motor coordination disability and acquired dysgraphia. Subsequent assessment research explained the graphia (letter forms through hand) in dysgraphia (disability in legible and automatic handwriting from memory associated with orthographic coding and/or finger sequencing impairments) occurring in developing learners within the normal range of cognitive abilities. Berninger (2001) drew on genetic, brain, assessment, and instructional research to explain the lexia in developmental dyslexia (disability in word level reading and spelling associated with impaired phonological and orthographic coding and/or loops of working memory) occurring in developing learners within the normal range of cognitive abilities. Programmatic research over two decades identified differences in the brain and genetic and behavioral phenotype markers of these biological bases in those with and without dysgraphia and dyslexia (Berninger & Richards, 2010; Berninger, Richards, & Abbott, 2015; Richards et al., 2015). So even if students with dyslexia have co-occurring dysgraphia (Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008), the brain and genetic bases for the co-occurring letter writing and reading disabilities do not have the same brain bases or necessarily the same exact behavioral markers (Berninger et al., 2015).

At present, difficulties with transcription for students with SLDs-WL have received relatively more research attention at the level of analyzing the composition product—the outcome of translation— rather than at the level of analyzing translation and planning processes during composing. Many studies for SLDs-WL have focused upon their spelling difficulties, which along with reading difficulties, are the hallmark characteristics of dyslexia (Nation, 2011). Researchers have shown that students with dyslexia struggle with translating orthographic codes into phonological codes in the oral reading direction (decoding) and with translating phonological codes into orthographic codes in the spelling direction (encoding) (Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008). Poor spelling skills contribute to a "double disadvantage" when writing (Connelly & Dockrell, 2016). First, less-accurate phonological and orthographic codes force writers to slow down as they labor to spell words, drawing upon cognitive resources that might be used elsewhere (Berninger et al., 2008). Second, students with dyslexia often choose "replacement" words for those they cannot spell, reducing the lexical diversity of their texts when compared to their oral productions (Sumner, Connelly, & Barnett, 2014). For students without dyslexia, spelling is a significant predictor of writing quality in grades 1-7 (Abbott, Berninger, & Fayol, 2010).

The difficulties faced by students with dysgraphia (impaired writing of letters by hand) may also affect word level spelling, but they do not impair word reading as in dyslexia (Berninger, Richards, & Abbott, 2015). It is important to note that students with dyslexia can also have letter production problems as well as word production problems, that is, co-occurring handwriting and spelling problems. What differentiates dyslexia and dysgraphia is the co-occurring word reading problems in dyslexia, but not dysgraphia. Difficulties in letter production have been shown to constrain writing fluency in text production in both students with SLDs-WL (Berninger et al., 2006) and typically developing writers (Alstad, Sanders, Abbott, Barnett, Henderson, Connelly, & Berninger, 2015).

Students with dysgraphia and dyslexia often struggle to develop automaticity when writing by hand, which can in turn interfere with composition length (number of words) and compositional fluency (rate of writing) as well as word-specific spelling (Berninger et al., 2015). At younger ages, handwriting automaticity accounts for as much as 67%

of the variance in text quality (Christensen & Jones, 2000), and even at the middle school level (adolescent writers), handwriting automaticity accounts for 16% of the variance in text quality (Berninger, 1999). Furthermore, difficulties with transcription have been shown to tax working memory resources, affecting the rate, length, and quality of writing produced (Bourdin & Fayol, 1994; Olive, Kellogg, & Piolat, 2008). However, recent work indicates that for students with dyslexia, slower writing production results not only from impaired letter production or slower handwriting speed, but also from more frequent and longer pauses during writing (hesitations or breaks) than age-matched peers (Sumner, Connelly, & Barnett, 2013). Overall, when compared to typically-developing peers, students with dyslexia consistently write shorter texts (Puranik, Lombardino, & Altmann, 2007), and generally produce texts rated lower in quality (Coleman, Gregg, McLain, & Bellair, 2009).

Given these transcription-level difficulties, all documented when students with dyslexia or dysgraphia write by hand, it is not surprising that alternative modes of writing have been suggested as accommodations. Chief among these accommodations is keyboarding, which allows writers to use word-processing software to bypass transcription difficulties related to handwriting. Dauite (1986) proposed that keyboarding, by making letter production simpler, may free up working memory resources, possibly leading to more (and better) writing overall. Keyboarding offers at least four potential advantages over handwriting. First, it is easier to revise texts, as word-processing software enables writers to add, delete, or move text easily. Second, with sufficient skill keyboarding can be faster, as button-pushes replace more elaborate hand and finger movements to produce letters. Third, the text produced is consistently legible, which is not always the case with younger students or those with transcription difficulties, and this may help with detecting spelling errors. Fourth, word processing software can provide a wide variety of supports for writers, ranging from spell-checking and grammar-checking to prompts for specific writing processes (such as prompts to review or revise).

Three meta-analyses investigating the effects of word processing upon writing found positive effects of word processing, which employed keyboards, on the length and quality of texts produced (Bangert-Drowns, 1993; Goldberg, Russell, & Cook, 2003). Bangert-Drowns (1993) found that text quality was higher in about two-thirds of the studies, with the largest improvements found for students with learning disabilities (MacArthur & Graham, 1987; Sitko & Crealock, 1986), elementary students (Phoenix & Hannan, 1984), and low-achieving students (Hannafin & Dalton, 1987; Robinson-Stavely & Cooper, 1990). Goldberg et al. (2003), focusing upon the effects of word processing with students from kindergarten to grade 12, reported similar effect sizes for overall text length (effect size = .50) and larger effects for text quality (effect size = .41). A third meta-analysis, focused upon weaker writers and word processing, found positive effects on several outcome measures (Morphy & Graham, 2012). Among these outcomes, positive effects were found for text length ($d$ = .48), text quality ($d$ = .52), development/organization of the text ($d$ = .66), and mechanical correctness ($d$ = .61).

Although the meta-analyses discussed above included studies with both typical and weaker writers (including some with SLDs), results are inconsistent among studies specifically investigating how keyboarding/word processing affects students with SLDs-WL. Connelly, Gee, and Walsh (2007) found advantages for handwriting over keyboarding in the early grades, for composing speed and compositional quality. Berninger, Abbott, Augsburger, and Garcia (2009) compared the effects of transcription mode (handwriting vs. keyboarding) with typically developing writers, ranging from second grade to fourth grade to sixth grade, and a group of fourth grade students with learning disabilities in writing. For the typically developing writers, they found advantages for handwriting over keyboarding for length of compositions and rate of composing, but individual differences among those with learning disabilities. Age (and perhaps keyboarding skill) appeared to make a difference; at least two studies have observed that the relative advantage of keyboarding over handwriting emerges during early adolescence (Christensen, 2004), especially in idea expression (Hayes & Berninger, 2010). However, MacArthur and Graham (1987) analyzed student texts composed by 5th and 6th grade students via handwriting, keyboarding, and dictation, and found no significant differences on several text measures (including length, quality, vocabulary, and T-unit length) between handwriting and keyboarding, although students tended to compose more quickly when writing by hand. Hollenbeck, Tindal, Stieber, and Harris (1999) found that for middle school students with SLDs, essays were rated higher on traits such as content, organization, ideas, and conventions when written by hand. For college students with and without SLDs, Berger and Lewandowski (2013) found that students in both groups wrote longer essays when word processing, and reported preferring composing by keyboard. Additionally, the effects of word-processing upon writing can differ depending upon whether the participants are writing over longer periods of time (with multiple drafts, as in 22 of the 27 studies reviewed in Morphy and Graham (2012) or are writing "on-demand" compositions within a shorter time period, as on a test (Russell & Plati, 2000). In general, as keyboarding skills increase, so too do the benefits of word processing (Christensen, 2004).

In drawing conclusions about the relative advantages of one transcription mode over another it is important to consider the types of writing tasks studied, the types of word-processing software used (whether software-level supports are included), and the characteristics of the participants (including their keyboarding skill). For example, in several of the studies in the meta-analyses mentioned above, writing instruction was provided to participants as they used word processing programs, whereas in others the word-processing software provided specific writing support, making it difficult to evaluate the specific effects of keyboarding. Overall, keyboarding appears to offer some advantages for typically developing writers, especially when paired with writing instruction, support for developing keyboarding skills, and opportunities to revise over time. For students with SLDs-WL research results are less clear, although the inconsistencies across studies for students appear to result, at least in part, on the developmental level of the participants (elementary-age students do not seem to benefit from keyboarding, whereas older students do) and individual differences in development of keyboarding skills (Berninger et al., 2009). Most of these studies, however, focus upon text products (such as length or quality) and overall writing time, measures which are less sensitive to moment-by-moment writing processes that are likely also influenced by writing mode. For example, when composing by hand, writers can view their emerging texts as they write. When keyboarding, touch-typists can view their texts as they compose, but less-skilled typists must alternate between viewing the keyboard when writing and viewing the screen (see Johansson, Wengelin, Johansson, & Holmqvist, 2010). As a result, patterns of composing, reviewing, and revising, including the frequency (and length) of writers' pauses, may be influenced by transcription mode (Van Waes & Schellens, 2003). Additional measures, specifically "on-line" measures that focus upon translation and transcription processes in combination with analyses of the written product, may provide new insights into how different transcription modes may affect students with and without SLDs-WL. Thus, additional research on alternative transcription modes in a sample of students during middle childhood and early adolescence with and without persisting SLDs-WL involving transcription disabilities seemed warranted.

## 2. On-line Writing Measures

Language bursts and pauses in written production have been studied in many on-line experiments of the composing process. Language bursts were first described by Kaufer, Hayes, and Flower (1986), who found that skilled adult writers generally produced writing in segments of about 9 words, punctuated by pauses of about two seconds. Building upon this work, Hayes and colleagues have shown that for adults, language bursts are strongly related to translation processes (Kaufer, Hayes, & Flower, 1986; Chenoweth & Hayes, 2001, 2003; Hayes & Chenoweth, 2007).

More recent studies have shown that transcription processes also contribute to language bursts, for adult writers (Alves, 2013; Alves, Castro, Sousa, & Stromqvist, 2007) and younger writers. For example, Alves and Limpo (2015) found that as transcription became increasingly automatized, burst lengths increased for students (in grades 2 to 7), and these increases were related to increases in overall writing fluency as well as text quality. Alves et al. (2012) suggested that more efficient transcription skills contribute to longer bursts by easing the cognitive demands of writing, allowing writers to capture larger language segments when transcribing them. Pauses in writing, which may be related to planning processes for the next language burst, and language bursts, created when the translation process generates the writer's thoughts into written language, have also received recent attention as a way to explore developmental aspects of the relationship of handwriting fluency to composing (Alves, Limpo, Fidalgo, Carvalhais, Pereira, & Castro, 2016; Alves & Limpo, 2015). However, pauses have also been linked to the composing fluency (speed) of those with dyslexia, who were found to pause more frequently (Sumner et al., 2013). Only one study of language bursts included students with specific language impairment (SLI). Connelly, Dockrell, Walter, and Critten (2012) found that compared to typically developing 11 year-olds, those with SLI produced shorter language bursts and their handwriting fluency and spelling accuracy were predictors of their burst length.

Several studies have also examined language bursts when keyboarding (Alves, Castro, de Sousa, & Stromqvist, 2007; Alves, Castro, & Olive, 2011; Hayes & Chenoweth, 2006). Alves et al. (2007) compared the language bursts composed by two adult groups writing narratives, one fluent at keyboarding and one with less keyboarding skill. Those with highly developed keyboarding skills composed in longer language bursts than those who typed more slowly, with average burst lengths of three additional words. In another study, Alves and colleagues (2011) randomly assigned 84 undergraduate students to one of four experimental conditions, designed to elicit fluent or disfluent transcription processes in handwriting and keyboarding. For the keyboarding conditions, students composed using either a typical QWERTY keyboard or a scrambled keyboard. In the low-fluency transcription condition, students composed in shorter language bursts than the high skill condition (of about six words less, on average), and the texts were rated lower in quality. As with handwriting, language bursts appear to be constrained when keyboarding processes are not automatized.

Overall, this review supports three relationships between transcription processes and language bursts as well as pauses. First, for both younger and older writers, transcription fluency is associated with longer language bursts. Second, longer language bursts are associated with better text quality, for handwriting and keyboarding. Third, at least two studies have shown differences between typically developing writers and those with dyslexia or SLI in their language bursts or pauses during writing. However, this review also reveals two striking gaps in the research literature. For example, the relationship between transcription ability and transcription mode has not been examined for middle childhood to adolescent students with persisting SLDs-WL (both dyslexia and dysgraphia). Also, no study to date has directly examined relationships between keyboarding and handwriting transcription modes and contrasting transcription disabilities in both composition products and on line composing processes as assessed by language bursts and pauses.

## 3. Tested Hypotheses and Methodological Approach of the Current Study

In the current study transcription was operationalized in two ways. First, participating students in grades 4 to 9 (spanning middle childhood to early adolescence) were assessed and assigned to diagnostic groups for typical language learners, dyslexia, or dysgraphia. Second, they were asked to compose personal narratives by pen and by keyboard. Effects of transcription ability (three diagnostic groups—one without transcription disability and two with contrasting transcription disabilities) and transcription mode (pen or keyboard) were compared on various outcomes during an on-line experiment.

Based upon the research reviewed, we made two predictions. The first hypothesis was that the group with dyslexia would produce more spelling errors in their written compositions, in both transcription modes, than either the typical control or dysgraphia group. The rationale was that spelling problems are a hallmark defining feature of dyslexia (Berninger et al., 2015), and would persist despite potential increases in word legibility when keyboarding. The second hypothesis was that, based upon the age of the participants (early adolescence), there would be significant main effects favoring keyboarding over handwriting (Christensen, 2004). Specifically, it was predicted that they would: write more words when keyboarding; write longer and write faster when keyboarding; and generate longer language bursts by keyboard, which reduces the time needed for letter production and thus increases time available for translation of ideas into written words.

Following comprehensive assessment of cognitive and oral and written language skills and related processes to determine if a student (in grades 4 to 9) was either a typically developing student or a student with persisting SLDs-WL, students were asked to participate in a study of on-line composing. Students composed autobiographical narratives in two composing modes: by hand, while using a stylus upon a digital tablet, and by keyboard. In both modes on-line text production data were collected, using a keystroke logging program (Inputlog) for keyboarding and a handwriting analysis software program (Eye and Pen). These software programs allowed us to measure language bursts, pauses in text production, and overall writing fluency, which were analyzed along with the text products.

## 4. Method

### 4.1 Participant Recruitment

Flyers distributed through local schools announced an opportunity to participate in research for students in grades 4 to 9 with and without SLDs in written language. Educators brought the opportunity to the attention of parents who if interested contacted the research team. Parents were then interviewed to rule out conditions other than SLDs, such as pervasive developmental disability, neurogenetic disorders like fragile-X or neurofibromatosis or PKU, a significant hearing loss or visual impairment, cerebral palsy or muscular dystrophy, spinal cord or brain injuries, substance abuse, and epilepsy or other seizure disorders, etc. If responses to the interview questions indicated the child probably had an SLD-WL, and the parent and child both granted assent, then comprehensive assessment was scheduled at the university. If that assessment confirmed that the student did or did not have dysgraphia or dyslexia, then the child was invited to participate in a related study involving an on-line writing experiment. The Institutional Review Board at the university where the research was conducted approved the flyers, the phone interview procedures, the assessment battery, and the on-line experiment.

## 4.2 Comprehensive, Multi-Modal Assessment

While the student completed the test battery, the parent completed questionnaires about developmental, medical, family, and educational history. Students, who all completed the same assessment battery, were assigned to diagnostic groups—typically developing language learners without SLDs-WL (control group) or students with SLDs—WL using evidence-based procedures based on programmatic research over three decades described in Berninger et al. (2015) and Sanders, Abbott, and Berninger (in press). These diagnostic procedures are based on profiles or patterns of skills, not a single one, and developmental and educational history including evidence that problems identified with tests are consistent with history and persisting over time despite intervention. The typical control group did not meet the criteria for either dysgraphia or dyslexia based on test scores or developmental or educational history. Use of measures normed for age allows for comparison of students across age levels within a study. Mean scores from these measures are reported in Table 1 below.

Consistent with procedures described in Berninger, Richards, and Abbott (2015), a standard score of 80 (– 1 1/3 SD which is lower limit of the normal range) on *WISC IV Verbal Comprehension Index* (Wechsler, 2003) was required for participation. Most scored in the average range (90 to 109), above average range (110 to 119), or superior to very superior range (120 to 140 and above), which is where 75% of the school-age population falls. In this section we describe only those measures in the assessment battery relevant to the diagnosis of dysgraphia, grouped by handwriting measures, or dyslexia, grouped by spelling and silent word reading measures. To qualify for a dysgraphia diagnosis, the evidence-based criteria used were below -2/3 *SD* (90 standard score or 8 scaled score) on two handwriting measures and parent reported current and past history of persisting handwriting problems (see Berninger et al., 2015). To qualify for a dyslexia diagnosis, the evidence-based criteria used were below -2/3 SD (90 standard score or 8 scaled score) on two or more spelling and word reading measures and parent reported current and past history of persisting word reading/decoding and spelling/encoding problems (see Berninger et al., 2015).

To assess students for impaired letter production, three measures of handwriting and one of keyboarding were included in the assessment battery.

### Automatic alphabet letter writing from memory in handwriting

This task instructs participants to handwrite in manuscript (unjoined letters) the lower case letters in alphabetic order from memory as quickly as possible without sacrificing legibility. The raw score is the number of legible letters in correct alphabetic order during first 15 seconds, which can be converted to a z-score (M=0, SD=1) based on research norms for grade (inter-rater reliability .97) for diagnostic purposes. For the current study, the raw score on this and the keyboarding version described next were compared; however, all other measures used had age norms.

### Automatic alphabet letter selection from memory by keyboarding

Participants were instructed to tap the keys of the alphabet (in order) from memory upon a facsimile of a keyboard as quickly as possible. The examiner recorded on a response record which key was tapped and the order in which each key was tapped. Raw scores for the number of correct keys tapped in the correct order in 15 seconds were calculated. All of the participants could produce the alphabet by keyboard by looking at the letters while selecting them, and none appeared to use the touch-type method of selecting letters without viewing the keys.

### Copying letters in words in sentences

Students also completed the *Detailed Assessment of Speed of Handwriting* (DASH) *Best and Fast* (Barnett, Henderson, Scheib, Schulz, 2007). The task is to copy a sentence which includes all the letters of the alphabet in one's best handwriting and also in one's fastest writing, using either —manuscript (unconnected) or cursive (connected) or a combination of these. Past research showed that word reading and spelling skills as well as handwriting skill may contribute to performance on a copy task (Berninger et al., 2015). In the current study, two testers reviewed all the scored handwritten measures to reach consensus on scoring; raw scores are converted into scaled scores (M=10, SD=3).

Because impaired spelling is a characteristic feature of dyslexia (Nation, 2011), three normed measures of spelling were given along with five normed measures of reading.

### Word-specific spelling (choosing or creating correct spellings for real words)

To assess word-specific spelling two spelling measures were given: *Letter-Choice* (test-retest reliability .84 to .88) of the Test of Orthographic Competence (TOC) (Mather, Roberts, Hammill, & Allen, 2008) on which task is to choose a letter in a set of four provided letters to fill in the blank in a letter series to create a correctly spelled real word (word-specific spelling); the TOC *Homophone Choice* (ages 9 to 12) or Word Choice (ages 13 to 16) (test-retest reliability .72 to .75) on which the task is to identify a correct spelling for a specific word. The raw score on both TOC subtests is converted to a scaled score (*M*=10, *SD*=3).

### Dictated spelling

*Wechsler Individual Achievement Test*, 3rd Edition (WIAT III) Spelling (Pearson, 2009) was given on which the task is to spell in writing dictated real words, pronounced alone, then in a sentence, and then alone (test retest reliability .92). The raw score on *WIAT III Spelling* is transformed into a standard score (*M*=100, *SD*=15).

***Table 1.*** Diagnostic Group Characteristics

| | Typically Developing | | Dysgraphia | | Dyslexia | |
|---|---|---|---|---|---|---|
| Measure | M | SD | M | SD | M | SD |
| Verbal Comprehension | 112.50 | 11.81 | 109.53 | 16.44 | 115.90 | 12.87 |
| Copy Sentence Best | 11.30 | 2.06 | 8.05 | 3.42 | 8.30 | 3.44 |
| Copy Sentence Fastest | 10.80 | 2.25 | 5.84 | 2.77 | 6.15 | 3.08 |
| TOC Letter Choice | 11.09 | 1.70 | 9.56 | 3.97 | 6.95 | 2.35 |
| TOC Word Choice | 12.43 | 3.05 | 11.00 | 3.24 | 9.21 | 2.72 |
| WIAT3 Spelling | 108.60 | 9.98 | 98.79 | 20.13 | 83.50 | 14.40 |
| TOSWF | 102.07 | 9.57 | 100.50 | 14.93 | 90.55 | 9.86 |
| WJ3 Word ID | 108.40 | 10.56 | 111.67 | 11.44 | 95.90 | 8.86 |
| WJ3 Word Attack | 106.53 | 10.51 | 107.78 | 12.53 | 93.50 | 7.71 |
| TOWRE Sight Words | 109.07 | 12.88 | 109.83 | 16.36 | 93.50 | 11.99 |
| TOWRE Phonemic Reading | 107.47 | 16.00 | 106.17 | 18.40 | 84.30 | 10.55 |
| | | | | | | |
| Additional Characteristics | | | | | | |
| Gender | | | | | | |
| Male | 9 | | 16 | | 15 | |
| Female | 6 | | 3 | | 5 | |
| Age | 149.2 | | 139.7 | | 143.6 | |
| Grade | 6.4 | | 5.8 | | 6.4 | |

***Notes*.**

N=54. Age is given in months as an average.
Verbal Comprehension = WISC IV Verbal Comprehension Index, scaled score.
Copy Sentence Best = Detailed Assessment of Speed of Handwriting (DASH) sentence copy in best handwriting task, scaled score.
Copy Sentence Fastest = Detailed Assessment of Speed of Handwriting (DASH) sentence copy in fastest handwriting task, scaled score.
TOC Letter Choice = Test of Orthographic Competence, choosing letters to create correctly spelled words, scaled score.
TOC Homophone/Word Choice = Test of Orthographic Competence, choosing correctly spelled words, scaled score.
WIAT3 Spelling = Wechsler Individual Achievement Test-Spelling, spelling dictated words, scaled score.
TOSWF = Test of Silent Word Reading Fluency, marking word boundaries in series of rows, scaled score.
WJ3 Letter/Word ID = Woodcock-Johnson, 3rd Ed., word identification of real words, scaled score.
WJ3 Word Attack = Woodcock-Johnson, 3rd Ed., word identification of pseudowords, scaled score.
TOWRE Sight Words = Test of Word Reading Efficiency sight word test, scaled score.
TOWRE Phonemic Reading = Test of Word Reading Efficiency, Pseudoword Efficiency test, scaled score.

To assess silent word reading accuracy and rate, the *Test of Silent Word Reading Fluency (TOSWRF)* (Mather, Hammill, Allen, & Roberts, 2004) (test-retest reliability is .92) on which the task is to mark the word boundaries in a series of letters arranged in rows, was given. To assess accuracy of oral reading of real and pseudowords, the *Woodcock Psychoeducational Battery 3rd Edition* (*WJ III*, Woodcock et al., 2001) *Word Identification* subtest (test-retest reliability .95), and the *WJ III Word Attack* subtest (test-retest reliabilities .73 to .81) were also given. To assess accurate and fast oral word reading and decoding, the *Test of Word Reading Efficiency (TOWRE)* (Torgesen, Wagner, & Rashotte, 1999) *Sight Word Efficiency Test* (test-retest reliability is .91) and *Pseudoword Efficiency Test* (test-retest reliability .90) were also given.

### Sample characteristics

Once assigned to a diagnostic group, the student and parent were invited to participate in a related on-line experiment using special computers. Altogether 54 parents consented and their children assented to participate in the related study (40 males and 14 females) ranging in age from 9 to 14 years old ($M$ = 11.98 years, $SD$ = 14.27). Of this group, 19 participants (35.2%) were in the dysgraphia group, 20 participants (37.0%) were in the dyslexia group, and 15 participants (27.8%) were in the typically developing language learner control group. See Table 1.

### Apparatus and material

For data collection, a 21-inch Wacom tablet was used in conjunction with an HP laptop along with a peripheral (standard QWERTY) keyboard for the typed portions of the study. For handwriting, a stylus was used with the same digital tablet after adjusting it to lay flat upon a table.

## 4.3 Procedures

All participants composed texts by hand (upon the digital tablet) and by keyboard. The investigator began by introducing the participant to the equipment, and providing ample practice in order to acquaint the child with the setting and to become comfortable writing on the digital tablet and using the keyboard. Directions were then given to the participant, including topics for the autobiographical narratives. Participants were given up to 10 minutes to compose each text, and could stop when they indicated they were finished (or when 10 minutes expired). Across the study, writing modes and text prompts were counterbalanced, with half of the participants randomly assigned to the handwriting condition first and the other half assigned to the keyboarding condition first (no order effects were found). In both conditions students could view a brief writing prompt at the top of the screen.

The topics were designed to be familiar to the students, and similar in level of challenge. The prompts were as follows: Prompt 1-"One purpose of writing is to express one's own ideas—my story. The topic of this writing activity is your story—the story of your life at school. Please tell your story about your life at school in writing." Prompt 2--"One purpose of writing is to express one's own ideas—my story. The topic of this writing activity is your life outside school right after school is over for the day. Please tell your story about your life after school is over in writing." No differences in text measures (such as text length) or online measures (such as language bursts) were found across narrative topics.

### 4.4 Data Analyses

Data were analyzed using a series of software programs. For the data collected during the keyboarding sessions, Inputlog software was used (Leijten & Van Waes, 2013). For the handwritten sessions, Eye and Pen version 2.0.0-70 was used for data collection and extraction (Alamargot, Chesnet, Dansac, & Ros, 2006). Eye and Pen is owned by CNRS and the University of Poitiers, 2004. After initial extraction, the data were then entered into a database using IBM SPSS Statistics Version 19.0.0.1, 2010.

### 4.5 Measures

#### Text production measures

A variety of text production measures were analyzed. These measures included overall words produced, overall composing time, words produced per minute, the number of pauses occurring per minute (pause frequency), the average pause length, and the percentage of spelling errors per text. To calculate composing time, average pause length, and words produced when keyboarding, Inputlog software was used. For the handwritten texts, composing time, average pause length, and words produced were calculated by Eye and Pen software. Spelling errors when keyboarding were identified using the spellcheck function in Microsoft word, along with a visual inspection by two researchers. For the handwritten texts, spelling errors were identified by two researchers, with 20% analyzed by both to determine interrater reliability (greater than 95%).

#### Pauses in production and language bursts during on-line composing

A pause was defined as a period of time in which no writing was produced, having a minimum duration of two seconds. A two second threshold was selected based upon prior studies of pauses and language bursts, in both studies of handwriting (Alves & Limpo, 2015; Alves, Limpo, Fidalgo, Carvalhais, Pereira, & Castro, 2016; Connelly, Dockrell, Walter, & Critten, 2012) and studies of keyboarding (Alves, Castro, de Sousa, & Stromqvist, 2007; Alves, Castro, & Olive, 2011; Hayes & Chenoweth, 2006). Although some have suggested different pause thresholds for keyboarding (i.e., Van Waes & Schellens, 2003; Schilperoord, 2001), a two second pause was selected because it has been found to be "sensitive to children's production rates and the involvement of high-level writing processes" (Alves et al., 2012. p. 394) and it allows for direct comparisons across writing modes. It is possible that a two second pause is appropriate only for writers at specific fluency levels, in either of the transcription modes, and analyses of pauses and language bursts may need to be tailored to specific writers engaging in specific writing tasks. Setting a shorter pause threshold (under two seconds) would likely lead to shorter language burst calculations, whereas a longer pause threshold (over two seconds) would likely lead to longer language burst calculations. Future research should explore the effects of different pause thresholds upon language bursts for writers at different fluency levels, in both handwriting and keyboarding.

After identifying pauses, language bursts were calculated, with a burst defined as the number of words produced in between pauses of two seconds or longer (with a minimum of one word produced). Inputlog and Eye and Pen software programs were used to identify pauses, and language bursts were then calculated manually (by counting words produced in between pauses). Language bursts were then averaged for each writing session, resulting in a measure of average burst length. Language bursts were calculated by two researchers, with 20% analyzed by both to determine interrater reliability (greater than 90%).

## 5. Results

A split-plot, 2 (handwriting; keyboarding) x 3 (dyslexia; dysgraphia; typically developing) mixed model ANOVA was used to test for differences across three diagnostic groups (transcription ability) and handwriting versus keyboarding (transcription mode), and to test for potential interactions between transcription ability and transcription mode. Mauchly's test of sphericity was not significant, so we report the unadjusted F-tests for the within-subjects effects and interaction tests. Table 2 reports descriptive statistics for each measure.

### 5.1 Main Effects for Diagnostic Group Based on Transcription Ability

As shown in Table 3, main effects were statistically significant for three outcomes from the on-line experiment: percent of incorrectly spelled words (transcription ability), $F(1,53) = 13.32$, $p < .01$, *partial* $\omega^2 = .34$; words produced per minute (composing fluency), $F(1,53) = 4.09$, $p = .02$, *partial* $\omega^2 = .14$; and length of language bursts (sustained translation bouts), $F(1,53) = 3.415$, $p = .04$, *partial* $\omega^2 = .12$. Note that the effect size was moderately high for spelling but lower for composing fluency and translation bouts.

As shown in Table 2, mean scores for these outcomes could consistently be ordered from best to worst across the diagnostic groups: the typical control group was better than the dysgraphia group, which was better than the dyslexia group. Follow-up pairwise comparisons showed that typically developing students made fewer spelling errors (as a percentage of total words) than those with dyslexia when keyboarding ($p < .01$) and handwriting ($p < .01$) and fewer errors than those with dysgraphia when keyboarding ($p < .01$) and handwriting ($p = .04$).

***Table 2.*** Descriptive Statistics by Diagnostic Group

| | Typically Developing | | | | Dysgraphia | | | | Dyslexia | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Handwriting | | Keyboarding | | Handwriting | | Keyboarding | | Handwriting | | Keyboarding | |
| Measure | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| Letter Writing | 14.33 | 2.72 | 16.93 | 9.25 | 12.18 | 4.61 | 18.24 | 6.77 | 12.05 | 4.35 | 16.75 | 4.76 |
| Total Words | 111.93 | 49.8 | 155.4 | 90.52 | 76.53 | 47.62 | 109.79 | 78.3 | 89.35 | 50.98 | 96.05 | 49.31 |
| Total Time | 428.05 | 145.75 | 485.43 | 104.18 | 384.28 | 151.04 | 443.51 | 127.61 | 429.52 | 136.08 | 468.44 | 150.1 |
| Words/Min | 16.62 | 7.33 | 18.88 | 9.31 | 12.14 | 5.31 | 14.93 | 8.52 | 12.02 | 4.11 | 12.54 | 4.58 |
| % Spelling Errors | 2.26 | 2.52 | 2.34 | 1.92 | 7.16 | 6.23 | 9.00 | 7.87 | 13.00 | 8.58 | 11.70 | 6.52 |
| Pause Length | 5.57 | 1.71 | 4.93 | 2.01 | 4.95 | 1.29 | 5.17 | 1.40 | 5.14 | 2.33 | 4.84 | 1.17 |
| Pauses/Min | 2.65 | 1.06 | 4.46 | 1.49 | 2.5 | 0.99 | 4.77 | 1.79 | 2.77 | 0.89 | 5.09 | 1.41 |
| Burst Length | 8.80 | 5.39 | 6.35 | 5.11 | 6.79 | 5.75 | 4.69 | 3.48 | 5.09 | 2.39 | 3.33 | 1.78 |

***Notes.***
Letter Writing = raw score, numbers of letters produced from memory in 15 seconds.
All time entries are given in seconds unless minutes are specified.
% Spelling Errors = the number of spelling errors divided by the total number of words per text.
Burst Length = the average number of words produced per language burst.

***Table 3.*** Mixed ANOVA Results

| | | F(1,53) | p |
|---|---|---|---|
| Diagnostic Group Effects | Letter Writing | .53 | 0.60 |
| | Total Words | 3.05 | 0.06 |
| | Total Time | 0.75 | 0.48 |
| | Words/Min | 4.08 | 0.02 |
| | % Spelling Errors | 13.32 | <.01 |
| | Pause Length | 0.13 | 0.88 |
| | Pauses/Min | 0.56 | 0.58 |
| | Burst Length | 3.42 | 0.04 |
| Mode Effects | Letter Writing | 19.78 | <.01 |
| | Total Words | 9.53 | <.01 |
| | Total Time | 5.41 | 0.02 |
| | Words/Min | 3.97 | 0.05 |
| | % Spelling Errors | 0.06 | 0.81 |
| | Pause Length | 0.51 | 0.48 |
| | Pauses/Min | 148.37 | <.01 |
| | Burst Length | 19.37 | <.01 |
| Group x Mode Interactions | Letter Writing | 0.97 | 0.39 |
| | Total Words | 1.69 | 0.06 |
| | Total Time | 0.09 | 0.91 |
| | Words/Min | 0.62 | 0.55 |
| | % Spelling Errors | 1.45 | 0.24 |
| | Pause Length | 0.79 | 0.46 |
| | Pauses/Min | 0.75 | 0.48 |
| | Burst Length | 0.18 | 0.84 |

Students with dygraphia had fewer errors than those with dyslexia when handwriting ($p$ = .01), but differences in spelling errors when keyboarding were not significant across these two groups.

Typically developing students wrote more words per minute when handwriting than those with dyslexia ($p$ = .02) and those with dysgraphia ($p$ = .02), and more words per minute than those with dyslexia when keyboarding ($p$ = .02). For language bursts, typically developing students wrote more words per burst than students with dyslexia when handwriting ($p$ = .02) and when keyboarding ($p$ = .02). Additionally, typically developing students wrote more words overall than those with dysgraphia when handwriting ($p$ = .05), and more words than those with dylexia when keyboarding ($p$ = .02).

### 5.2 Main Effects for Transcription Mode

Five outcomes from the on-line experiment yielded statistically significant effects for writing mode: total word count, $F(1,53) = 9.53$, $p < .01$, *partial* $\omega^2 = .16$; total composing time, $F(1,53) = 5.41$, $p = .02$, *partial* $\omega^2 = .10$; words per minute, $F(1,53) = 3.97$, $p = .05$, *partial* $\omega^2 = .07$; pauses per minute, $F(1,53) = 148.37$, $p < .01$, *partial* $\omega^2 = .74$; and length of language bursts $F(1,53) = 19.37$, $p < .01$, *partial* $\omega^2 = .28$. Note that the effect size was large for pauses per minute, low for total word count, total time composing, and words per minute, and moderate for length of language bursts. As shown in Table 2, across diagnostic groups, keyboarding led to longer texts and longer composing times, but also more pauses in text production and shorter language bursts.

Additionally, data from tasks given in the initial assessment process were analyzed to determine if automaticity of writing the alphabet from memory was related to transcription mode. For raw scores on these tasks of letter production (via handwriting and keyboarding), a significant main effect was found, $F(1,53) = 19.78$, $p < .01$. As shown in Table, 2, students consistently produced more letters from memory in a timed condition when keyboarding than when handwriting.

None of the interactions between diagnostic group for transcription ability and transcription mode was statistically significant.

## 6. Discussion

To investigate the effects of transcription ability on the translation process in students in grades 4 to 9 with and without transcription disabilities, measured variables in written text products (text length, total time of composing, words per minute/compositional fluency, and percentage of spelling errors) and on-line measures for pauses and language bursts were compared for three diagnostic groups (typical controls, dyslexia, and dysgraphia) and two transcription modes (handwriting and keyboarding). In general results provided evidence for the tested hypotheses, but also included evidence in support of relationships not predicted.

### 6.1 First Tested Hypothesis and Conceptual Frameworks for Writing

The first hypothesis, that the group with dyslexia would produce a higher percentage of spelling errors across both transcription modes than either the typical control or dysgraphia group, was mostly supported. First, there was a main effect for diagnostic group on the percentage of spelling errors during the on-line composing task. When the three diagnostic groups were compared, the dyslexia group produced a significantly higher percentage of spelling errors in their handwritten products than either the typical control or dysgraphia group. When keyboarding, the dyslexia group produced a significantly higher percentage of spelling errors than the typically developing group (the difference between the dyslexia group and the dysgraphia group did not reach significance for keyboarding). Additionally, two other main effects for diagnostic groups were consistent with prior research; for rate of composing (compositional fluency as measured in words per minute) and length of language bursts (conceptualized as an indicator of translation) the typical control group had better scores than the dyslexia group. Thus, across transcription modes, word level spelling may play an even more important role in transcription than letter level production and contribute more to the relationships between transcription and translation. Even though the automatic letter writing impairments in dysgraphia may interfere with spelling acquisition, the word spelling problems in developmental dyslexia are more persisting and difficult to remediate (Berninger et al., 2008; Sanders et al., in press). In addition, the effect size was larger for the percent of spelling errors across groups than it was for words per minute and length of language bursts. This finding is consistent with the idea that transcription is a separable process from translation, and that transcription problems can influence translation, with spelling having perhaps the largest influence. In fact, a brain imaging study showed that a region associated with cognition was activated on a spelling but not handwriting task (Richards, Berninger, & Fayol, 2009). The outcomes for which there was not a significant main effect for diagnostic group related to transcription ability (automatic letter writing from memory) have been shown in other research to be related to handwriting processes rather than spelling (Berninger et al., 2006).

### 6.2 Second Tested Hypothesis and Conceptual Frameworks for Writing

The second hypothesis tested, that there would be significant main effects for transcription mode favoring keyboarding for total words, total time composing, rate (words per minute; writing fluency) and length of language bursts, was supported for the first three outcomes. That the texts composed using keyboarding were on average longer than by handwriting is consistent with prior research for typically developing students and weaker writers (Goldberg, Russell, & Cook; Morphy & Graham, 2012) of students in this age range (Christensen, 2004). That total time engaged in composing was longer and writing rate (fluency) was greater on average by keyboard than by handwriting is consistent with the idea that letter selection on keys requires less resources than letter production by hand.

However, the hypothesis was not supported for the last outcome: average length of language bursts, which favored handwriting over keyboarding. A possible explanation of the advantage of handwriting for length of language bursts is that the act of forming letters engages cognitive processes such as idea generation and planning, supporting ongoing translation processes that lead to longer language bursts. Another explanation may be that when writing by hand, students generally view the letters and words they are creating as they compose (Breetvelt, van den Bergh, & Rijlaarsdam, 1996; Pianko, 1979; Stallard, 1974). Reviewing previously written text can support planning processes, as writers seek to build upon prior ideas, as well as translation processes (mapping ideas onto appropriate syntactic units and words) and transcription processes (making sure words are correctly spelled and letters are formed clearly). Additionally, reviewing the most recently composed words may help keep linguistic units active in working memory, which is limited by capacity constraints and competing writing processes (McCutchen, 1996). For adolescent writers, reviewing the text produced so far has been associated with text quality (Beers, Quinlan, & Harbaugh, 2011). If reviewing recently composed words supports translation and transcription processes, longer language bursts may result.

Along with composing in shorter language bursts, students exhibited more pauses per minute when keyboarding, with transcription mode having an effect size of .74. When keyboarding, at least until a high degree of proficiency is attained (as with touch-typists), students appear to review their texts differently when compared to handwriting. Instead of reviewing recently composed letters and words as they appear on screen, writers of low to moderate keyboarding skill (as in this study) look at their hands as they type, and only review their texts during pauses. With adult writers, these differences were observed in an eye movement study, with "monitor gazers" (touch typists) reviewing their texts more frequently than "keyboard gazers" (Johansson, Wengelin, Johansson, & Holmqvist, 2010). Although in this study an analysis of the final texts showed no differences between the groups, these results might be different for younger writers or those with less writing skill. If younger writers frequently shift between composing processes (including translation and transcription) and reviewing processes, it is possible that translation processes might be interrupted if writers suspect that a word was typed incorrectly and stop to check. When keyboarding, students also need to keep translated language units active in working memory while typing them, without any visual reinforcement. Future research employing eye tracking methods may clarify how keyboarding influences writer-text interactions.

## 6.3 Limitations

Students were writing first drafts only, on topics with which they were familiar (describing life at school, or after-school activities) but not necessarily motivated to write about. Furthermore, because the audience for these texts was the research team, the writing task was not an "authentic" one, and we may not have received the students' best efforts. At the same time, these tasks were not remarkably different from typical school-based writing assignments, which include narrative as well as expository genres. Results of the current study can be generalized, however, only to personal narrative composing, and to students in the middle childhood to early adolescent age range. Future studies could incorporate not only additional genres but also both first drafts and revising sessions, exploring whether language bursts produced during revising activities are different.

The current study did not analyze composition quality because that is a focus of the intervention studies in which some of the children in the current study also subsequently participated; and response to intervention is not evaluated based on ratings of quality but rather other constructs such as idea units, use of Level I translation strategies (next sentence) and Level II translation strategies (evolving discourse structure), or use of notes in writing summaries of source material (published studies available upon request from last author). Also, we did not distinguish between bursts according to events preceding them or following them (such as a pause or revision), and it is possible that bursts are influenced differently depending upon the cognitive processes occurring at burst boundaries. However, revisions were infrequent among these student writers, as has been reported elsewhere (Berninger & Swanson, 1994), and almost never occurred in this study, so most bursts were punctuated by pauses.

Finally, it should be noted that the word processing software used for the keyboarding condition was limited to text production features only, with other potentially helpful features (such as spelling checks, grammar checks, and prompts for revising) disabled. Although this was done to make the handwriting and keyboarding conditions as similar as possible, other studies have reported powerful effects upon text quality when these additional features were available (see Morphy & Graham, 2012). It is possible that the advantages provided by these word processing programs might outweigh other potential disadvantages when keyboarding. Future research efforts comparing the effectiveness of different types of writing software supports might illuminate specific features that benefit writers with SLDs-WL.

### 6.4 Educational Implications

In the current study main effects were found for diagnostic group based on transcription ability (typical or meeting evidence-based criteria for primary handwriting disability or primary word spelling disability) and transcription mode (handwriting or keyboarding) on outcomes related to transcription and translation in composition products and on-line composing processes contributing to those products. A significant main effect for diagnostic group (transcription ability) was found for percent of spelling errors in composing products but not for automatic letter production across writing modes (handwriting vs. keyboarding). It appears that impaired word spelling may interfere with composing even more than impaired handwriting. Moreover, across transcription ability groups, a main effect for transcription mode favoring keyboarding was found for automatic alphabet letter writing, total words, total time composing, and composing rate (writing fluency). A main effect favoring handwriting was found for length of language bursts.

The educational implications of these collective findings are two-fold. First, writing instruction should incorporate systematic instruction in spelling at each grade level throughout middle childhood and adolescence to facilitate the writing achievement of students. Spell-checking software and other technological tools are not a substitute for ongoing systematic spelling instruction, because transcription is related to translation. Second, writing instruction should prepare students to become "hybrid" writers with expertise in both handwriting and keyboarding—each has relative advantages for the transcription processes that contribute to translation. Students in this study looked at their hands when composing via keyboarding, interfering with their ability to review their translation products on the computer screen while writing. Touch typing should also be taught and reviewed throughout the secondary and postsecondary years of schools. For example, Alves et al. (2007) found that undergraduate students with high typing skill wrote texts with longer bursts than those with lower skill. When writers become touch-typists, and can view their texts while composing them, translation processes may be facilitated.

Additionally, the results have application to assessment and instruction for students with SLDs-WL. These students are typically assessed only on the basis of their written composition products, but may also benefit from the assessment of their on-line processes during translation and related transcription processes. Numerous studies have shown that students with dyslexia exhibit lower writing fluency than their typically developing peers, as they struggle to spell words (Berninger at al., 2008), pause more frequently (Sumner, Connelly, & Barnett, 2013), write shorter language bursts (Connelly, Dockrell, Walter, & Critten, 2012), and write fewer words overall. Students with dysgraphia may also, however, benefit from specialized assessment as well as instruction beyond simply recommending keyboards and computers as an accommodation, including but not restricted to touch typing (Thompson et al., 2016).

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